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Indian Standard

OPTICS AND OPTICAL INSTRUMENTS — LASERS AND LASER-RELATED EQUIPMENT — VOCABULARY AND SYMBOLS

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Optical and Mathematical Instruments Sectional Committee, LM 20

NATIONAL FOREWORD

This Indian Standard which is identical with ISO 11145 : 1994 'Optics and optical instruments — Lasers and laser-related equipment—Vocabulary and symbols', issued by the International Organization for Standardization (ISO), was adopted by the Bureau of Indian Standards on the recommendation of the Optical and Mathematical Instruments Sectional Committee (LM 20) and approval of Light Mechanical Engineering Division Council.

Lasers are being increasingly used in the field of medical, defence and other engineering applications. This standard is intended to provide a uniform interpretation and usage of various technical terms and symbols associated with lasers and laser related equipment.

ISO 11145 : 1994 has been published in dual language, that is, English and French. This adopted Indian Standard is being published in English only and text given in French has been deleted.

The text of ISO Standard has been approved as suitable for publication as Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as Indian Standard, and

b) Comma (,) has been used as a decimal marker while in Indian Standards the current practice is to use a point (.) as the decimal marker.

Indian Standard

OPTICS AND OPTICAL INSTRUMENTS — LASERS AND LASER-RELATED EQUIPMENT — VOCABULARY AND SYMBOLS

1 Scope

This International Standard defines basic terms, symbols and units of measurement for the field of laser technology in order to unify the terminology and to arrive at clear definitions and reproducible tests of beam parameters and laser-oriented product properties.

2 Symbols and units of measurement

2.1 The spatial distribution of power (energy) density of a laser beam does not always have circular symmetry. Therefore, all terms related to these distributions are split into those for beams with circular and those with non-circular cross-sections. A circular beam is characterized by its radius, w, or diameter, d. For a non-circular beam, the beam widths, d_x and d_y, for two orthogonal directions have to be given.

2.2 The spatial distributions of laser beams do not have sharp edges. Therefore, it is necessary to define the power (energy) values to which the spatial terms refer. Depending on the application different cut-off values can be chosen (for example, $1/e$, $1/e^2$, $1/10$ of peak value).

To clarify this situation, this International Standard uses the subscript u for all related terms to denote the percentage of the total beam power (energy) taken into account for a given parameter.

NOTE 1 For the same power (energy) content, beam width $d_{x,u}$ and beam diameter d_u ($=2w_u$) may differ for the same value of u (for example, for a circularly symmetric Gaussian beam $d_{86.5}$ is equal to $d_{x,95.4}$).

Table 1 lists symbols and units which are defined in detail in clause 3.

Table 1 — Symbols and units of measurement

Symbol	Unit	Term
A	m^2	beam cross-sectional area
E	W/m^2	average power density
H	J/m^2	average energy density
K		beam propagation factor
P	W	cw-power
p_{av}	W	average power
P_{pk}	W	peak power
P_H	W	pulse power
Q	J	pulse energy
d	m	beam diameter
d_0	m	beam waist diameter
d_x	m	beam width in x-direction
d_y	m	beam width in y-direction
f_p	Hz	pulse repetition rate
l_c	m	coherence length
p		degree of linear polarization
w	m	beam radius
w_0	m	beam waist radius
$w_{0\cdot\theta/2}$	rad.m	beam parameter product
z_R	m	Rayleigh length
θ	rad	divergence angle
θ_x	rad	divergence angle for x-direction
θ_y	rad	divergence angle for y-direction
η_L		laser efficiency
η_Q		quantum efficiency
η_T		device efficiency
τ_H	s	pulse duration
τ_{10}	s	10%-pulse duration
τ_c	s	coherence time
λ	m	wavelength
$\Delta\lambda_H$	m	spectral bandwidth in terms of wavelength
$\Delta\nu_H$	Hz	spectral bandwidth in terms of optical frequency

3 Definitions

3.1 beam axis: Straight line connecting the centroids defined by the first spatial moment of the cross-sectional profile of power (energy) at successive positions in the direction of propagation in a homogeneous medium.

3.2 beam cross-sectional area, A_u: Smallest area containing u% of the total beam power (energy).

NOTE 2 The area of a beam with circular cross-section can be calculated from πw_u^2.

3.3 beam diameter, d_u: Diameter of an aperture in a plane perpendicular to the beam axis which contains u% of the total beam power (energy).

NOTE 3 Another definition of beam diameter, d_σ, based on the second moment of the cross-sectional profile of power (energy), exists in ISO/CD 11146[1]. It is expected that this definition will eventually be included in this International Standard, along with the definition already given above.

3.4 beam radius, w_u: Radius of an aperture in a plane perpendicular to the beam axis which contains u% of the total beam power (energy).

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[1] ISO/CD11146 : *Optics and optical instruments — Test methods for laser beam parameters — Beam widths, divergence angle and beam propagation factor.*

3.5 beam width, $d_{x,u}$, $d_{y,u}$: Width of the smallest slit transmitting u% of the beam power (energy) in two preferential orthogonal directions x and y which are perpendicular to the beam axis. The preferential directions are given by the smallest beam width and the orthogonal direction.

NOTE 4 Other definitions of beam width, $d_{\sigma x}$ and $d_{\sigma y}$, based on the second moment of the cross-sectional profile of power (energy), exist in ISO/CD 11146[1]. It is expected that these definitions will eventually be included in this International Standard, along with the definitions already given above.

3.6 beam parameter product, $w_0 . \theta/2$: Product of the beam waist radius, w_0, and the half divergence angle, $\theta/2$.

3.7 beam position: Displacement of the beam axis relative to the fixed mechanical axis of an optical system at a specified plane perpendicular to the mechanical axis of the optical system. The mechanical axis is given by the straight line joining the centroids of the limiting apertures.

3.8 beam positional stability: Maximum parallel displacement and/or angular motion of the beam away from an average, steady-state position.

3.9 beam propagation factor, K: Measure of how close the beam parameter product is to the diffraction limit of a perfect Gaussian beam. It is calculated from the formula:

$$K = \frac{\lambda}{\pi} \times \frac{4}{d_0 \theta}$$

It is equal to the quotient of the beam parameter products for the fundamental Gaussian mode (TEM_{00}) and the actual mode of the laser.

The beam propagation factor is unity for a theoretically perfect Gaussian beam, and has a value between one and zero for any real beam.

NOTE 5 Values for d_0 and θ here relate to the beam width containing 86,5% of total beam power (energy).

3.10 beam waist: Local minimum of the beam diameter or beam width.

3.11 beam waist diameter, $d_{0,u}$: Diameter of the beam at the location of the beam waist.

3.12 beam waist radius, $w_{0,u}$: Radius of the beam at the location of the beam waist.

3.13 coherence: Characteristic of an electromagnetic field where there is a constant phase relationship between each point.

3.13.1 temporal coherence: Characteristic of the correlation of the phases of a signal for different times at the same location.

3.13.2 spatial coherence: Characteristic of the correlation of the phases of a signal at different locations at the same time.

3.14 coherence length, l_c: Distance in beam direction within which the radiation emitted by the laser retains a significant phase relationship. It is given by $c/\Delta \nu_H$ where c is the velocity of light.

3.15 coherence time τ_c: Time interval within which the radiation emitted by the laser retains significant phase relationship. It is given by $1/\Delta \nu_H$.

3.16 device efficiency, η_T: Quotient of the total power (energy) in the laser beam and the total input power (energy) including all subordinate systems.

3.17 divergence angle, $\theta; \theta_\lambda; \theta_x; \theta_y; \theta_{x,u}; \theta_{y,u}$: Full angle formed by the asymptotic cone of the envelope formed by the increasing beam width.

For a circular cross-section, the beam width is given by the beam diameter. For noncircular cross-sections, the divergence angles are separately determined by the corresponding beam width in x- and y-directions, respectively.

When specifying divergence angles, subscripts should be used to indicate the relevant beam width (for example: $\theta_{x,50}$ indicates that beam width $d_{x,50}$ has been used).

3.18 effective ***f*****-number**: Ratio of focal length of an optical component to beam diameter ($d_{86,5}$) at that component.

3.19 average energy density, H_u: Total energy of a beam divided by the cross-sectional area, A_u, of the beam.

3.20 pulse energy, Q: Energy in one pulse.

3.21 far-field: Radiation field of a laser at a distance z from the beam waist which is much greater than 50 times the Rayleigh length z_R.

3.22 laser: Lasers consist of an amplifying medium capable of emitting coherent radiation with wavelengths up to 1 mm by means of stimulated emission (see figure 1).

3.23 continuous wave (cw) laser: Laser operating and continuously emitting radiation over periods of time greater than or equal to 0,25 s.

3.24 pulsed laser: Laser which delivers its energy in the form of a single pulse or a train of pulses. The duration of a pulse is less than 0,25 s.

3.25 laser assembly: Laser device together with specific, normally optical, mechanical and/or electrical system components for beam handling and forming (see figure 1).

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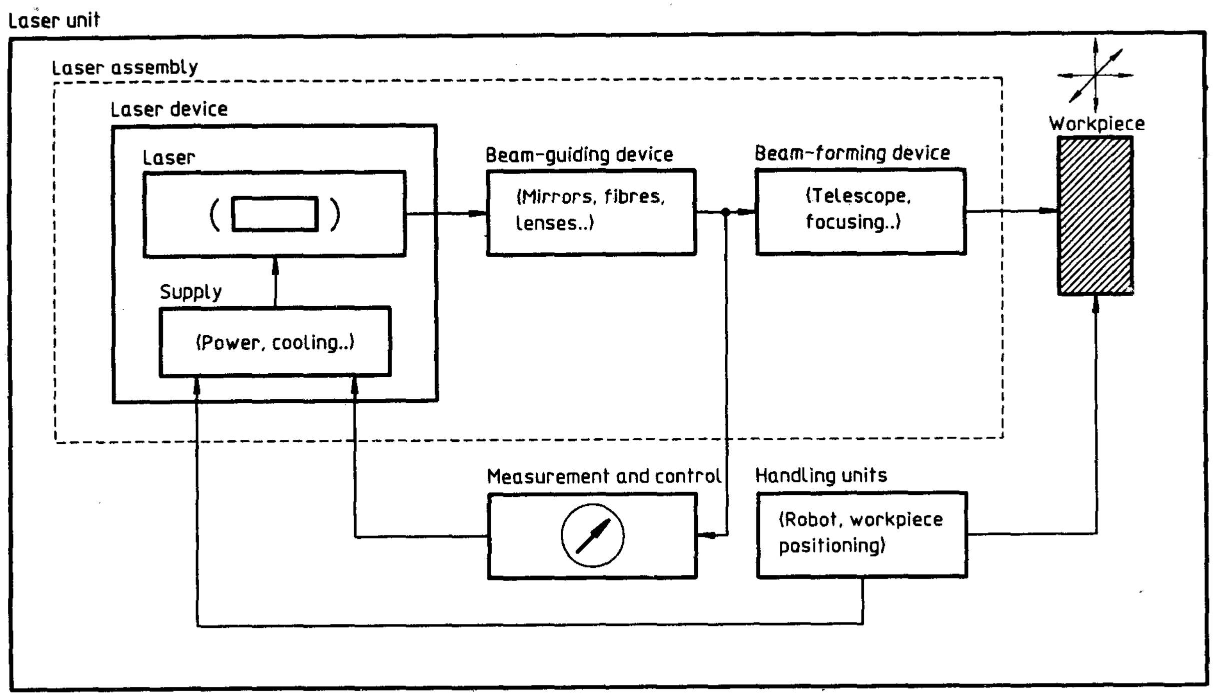
[1] ISO/CD 11146, *Optics and optical instruments — Test methods for laser beam parameters — Beam widths, divergence angle and beam propagation factor.*



NOTES

1 This example is taken from materials processing.

2 Safety equipment also usually needed is not included here.

Figure 1 — Illustration of the terms laser, laser device, laser assembly and laser unit

3.26 laser beam: Spatially directed laser radiation.

3.27 laser device: A laser, where the radiation is generated, together with essential additional facilities (e.g. cooling, power and gas supply) that are necessary to operate the laser (see figure1).

3.28 laser efficiency, η_L: Quotient of the total power (energy) in the laser beam and the pump power (energy) which is directly supplied to the laser.

3.29 laser radiation: Coherent electromagnetic radiation with wavelengths up to 1 mm, generated by a laser.

3.30 laser unit: One or more laser assemblies together with handling, measurement and control systems (see figure 1).

3.31 lifetime: Interval (time or number of pulses) over which a laser device or a laser assembly maintains the performance characteristics specified by the manufacturer. Conditions of use, service and maintenance are specified by the manufacturer.

3.32 longitudinal mode: Eigenfunction of the electric field distribution within a resonator of length L along the direction of propagation of the electromagnetic wave. The longitudinal mode number $q = 2L/\lambda$ describes the behaviour in the direction of propagation, or more specifically the number of half-wavelengths of the standing wave between the mirrors.

3.33 transverse mode: Eigenfunction of the electric field distribution within the resonator or of the intensity distribution of the laser beam perpendicular to the direction of propagation of the electromagnetic wave. For rectangular symmetry, the numbers m, n account for the nodes in the field distribution in the x-, and y-directions, perpendicular to the direction of propagation of the electromagnetic wave (Hermite-Gauss modes). For cylindrical symmetry, p and l account for the radial and azimuthal nodes (Laguerre-Gauss modes).

3.34 circular polarization: Description of a radiation wave in which the electric vector is of constant amplitude and rotates about the direction of propagation at a frequency equal to the radiation frequency in a homogeneous optical medium.

3.35 elliptical polarization: Description of a radiation wave in which the electric vector rotates at the radiation frequency but varies in amplitude in a homogeneous optical medium. The terminal point of the electric vector describes an ellipse.

3.36 linear polarization: Description of a radiation wave in which the electric field vector is at a fixed azimuth i.e. it is confined to a plane containing the direction of propagation of the radiation in a homogeneous optical medium.

A laser beam is called "linearly polarized" if the degree of linear polarization is greater than 0,9 and the polarization direction is constant in time.

3.37 degree of linear polarization, p: Ratio of the difference to the sum of beam powers p (energies Q) in two orthogonal directions of polarization i.e.

$$p = \frac{P_x - P_y}{P_x + P_y} \quad \text{or} \quad p = \frac{Q_x - Q_y}{Q_x + Q_y}$$

The directions x and y are chosen as those for which the beam power (energy) is attenuated minimally or maximally, respectively, after transmission through a linear polarizer.

The direction x, for which the beam attenuation after transmission through a linear polarizer is minimal, is the polarization direction.

3.38 partial polarization: State in which a beam of radiation whether originating from a natural or artificial source, is neither completely polarized nor completely unpolarized. A partially polarized beam can be regarded as being composed of two components, one polarized and the other unpolarized.

A laser beam is called "partially linearly polarized" if the degree of linear polarization is greater than 0.1 and the polarization direction is constant in time.

3.39 randomly polarized radiation: Radiation that can be considered as the composition of two orthogonal linearly polarized waves of fixed directions whose amplitudes vary randomly over time with respect to each other.

3.40 unpolarized radiation: Radiation whose intensity, when transmitted through any polarizer, wave retarder or rotator, is insensitive to the setting of this device.

It can be considered as the superposition of different random states of polarization.

3.41 average power density, E_u: Total power of a beam divided by the cross-sectional area A_u of the beam.

3.42 cw-power, P: Power output of a cw-laser.

3.43 pulse power, P_H: Quotient of the pulse energy Q and the pulse duration τ_H.

3.44 average power, P_{av}: Product of the average pulse energy Q and the pulse repetition rate f_p.

3.45 peak power, P_{pk}: Maximum of the power-time function.

3.46 pulse duration, τ_H: Interval between the times when the instantaneous power reaches 50 percent of the peak power for the first and the last time.

3.47 10%-pulse duration, τ_{10}: Interval between the first and last times when the pulse reaches 1/10 of the peak power.

3.48 pulse repetition rate, f_p: Number of laser pulses per second of a repetitively pulsed laser.

3.49 quantum efficiency, η_Q: Quotient of the energy of a single laser photon and the energy of a single pumping photon which causes the inversion in an optically pumped laser.

3.50 Rayleigh length, z_R: Distance from the beam waist in the direction of propagation for which the cross-sectional area is twice that at the beam waist.

For the Gaussian fundamental mode:

$$z_R = \pi d_0^2/4\lambda$$

Generally the formula $z_R = d_0/\theta$ is valid.

3.51 spectral bandwidth, $\Delta\lambda_H$, $\Delta\nu_H$: Maximum difference between the wavelengths (optical frequencies) for which the spectral power (energy) density is half of its peak value.

3.52 stable resonator: Resonator with two terminating mirrors, the paths of the paraxial rays of which remain within the resonator for an infinite number of round trips.

3.53 unstable resonator: Resonator with two terminating mirrors, the paths of the paraxial rays of which escape from the resonator after a finite number of round trips. However, one axial ray stays in the resonator as long as diffraction is neglected.

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